

300-2397  
NASA Contractor Report 159231

# Flight Service Evaluation of Kevlar-49 Epoxy Composite Panels in Wide-bodied Commercial Transport Aircraft

## Sixth Annual Flight Service Report

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BURBANK, CALIFORNIA

CONTRACT (NAS1-11621)  
March 1980

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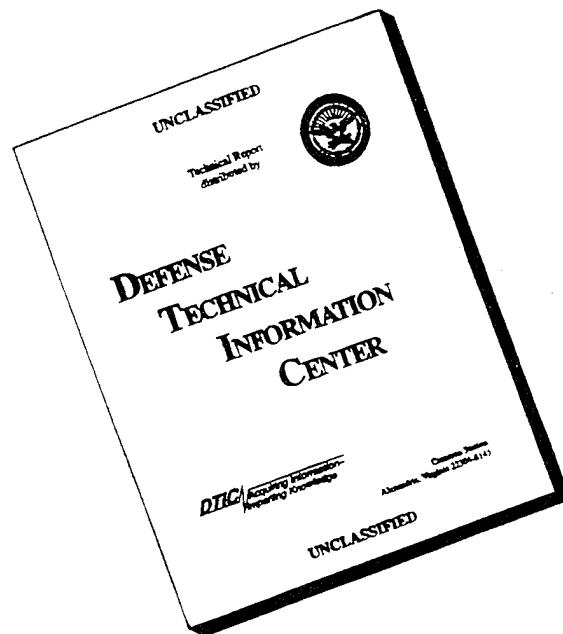


National Aeronautics and  
Space Administration

**Langley Research Center**  
Hampton, Virginia 23665  
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FLIGHT SERVICE EVALUATION  
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## FOREWORD

This is the sixth annual flight service evaluation report on the condition of Kevlar-49 fairing panels installed on three L-1011s under NASA Contract NAS 1-11621, "Flight Service Evaluation of Kevlar-49 Composite Panels in Wide-Body Commercial Transport Aircraft." The manufacture and installation of these panels was completed in February 1973 and reported in NASA CR-112250 dated March 1973 (ref. 1). The results of inspections after the first 5 years of flight service were reported in refs. 2, 3, 4, 5 and 6. The original 5-year flight service program was extended for an additional 5 years through 1983. Annual reports will be issued describing service performance after each year of service through the 10 year duration of the program.

This program is being administered by the Langley Research Center, National Aeronautics and Space Administration, with Mr. Benson Dexter of the Materials Division as the Project Engineer.

This program is being performed by the Lockheed-California Company with Robert H. Stone the Program Leader, assisted by T. L. Crawford of the Product Support Branch.

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*D. E. STONE  
SUPPORT MANAGER*

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FLIGHT SERVICE EVALUATION OF KEVLAR-49  
EPOXY COMPOSITE PANELS ON AIRBUS AIRLINES  
COMMERCIAL TRANSPORT AIRCRAFT

Smith Aerospace Flight Service Department

INTRODUCTION AND BACKGROUND

The subject program on flight service evaluation of Kevlar-49 fairings consists of fabrication, installation, and flight service evaluation of six secondary structural panels on each of three I-101's. The three participating airlines are Eastern, TWA, and Air Canada. Fabrication and installation of the panels was completed in February 1973, with initiation of flight service occurring in early 1973 on all three aircraft.

In all of the prototype fairings, Kevlar-49 fabric comparable in fabric weave and thickness per ply to the baseline fiberglass, was substituted for the fiberglass on a ply-for-ply basis. This required no other design changes or development of new tooling for layup and cure, but still provided a savings in component mass of 25-30 percent. These six parts are as follows:

- o A left-hand and right-hand set of a large 152-cm (60-in.) by 170-cm (60-in.) sandwich wing body fairing panel. The exterior skin is 0.05 cm (0.02 in.) thick with one ply of 181 style Kevlar-49 fabric and two plies of 120 style Kevlar-49 fabric. The dimension skin is 0.04 cm (0.015 in.) thick with three plies of 120 style Kevlar-49 fabric. The honeycomb core is Nomex with 0.3 cm (1/8 in.) cells, and 0.05 gm/cm<sup>3</sup> (3.0 lb/cu ft) density. Overall panel thickness is 2.24 cm (0.88 in.), with a solid laminate edge 0.25 cm (0.10 in.) thick, built up of 181 style Kevlar-49 plies (figure 1).
- o A left-hand and right-hand set of a small 23-cm (9-in.) by 33-in.) solid laminate wing-body filler panel. The laminate incorporates nine plies of 181 style Kevlar-49 fabric and is approximately 0.25 cm (0.1 in.) thick (figure 2).
- o A left-hand and right-hand pair of an aft engine sandwich fairing 76-cm (30-in.) by 183-cm (72-in.) approximately. The skins are 0.05 cm (0.02 in.) thick with one ply of 181 style Kevlar-49 fabric and two plies of 120 style Kevlar-49 fabric. The Nomex core is identical to that used in the wing body fairing except for thickness, and the overall panel thickness is 0.14 cm (0.56 in.). The aft engine fairing also has a solid laminate edge member 0.25 cm (0.10 in.) thick (figure 3).

The Kevlar-49 panels used the same resin system as the production fiber-glass parts. A 394 K ( $250^{\circ}\text{F}$ ) curing, 355 K ( $180^{\circ}\text{F}$ ) service epoxy (Hexcel's F-155) was used in the wing-body fairing and under-wing fillet panels; and a 450 K ( $350^{\circ}\text{F}$ ) curing, 422 K ( $300^{\circ}\text{F}$ ) service epoxy (Hexcel's F-161) was used in the aft engine fairings. Two fabric weave styles of Kevlar-49 were used. The Kevlar-49 style 181 is an 8-harness satin weave similar to the 181 fiber-glass weave, 0.23 mm (9 mils) per cured ply and  $0.17 \text{ kg/m}^2$  ( $5.0 \text{ oz/yd}^2$ ) dry mass. Kevlar-49 style 120 is a plain weave, 0.13 mm. (5 mils) per cured ply and  $0.06 \text{ kg/m}^2$  ( $1.8 \text{ oz/yd}^2$ ) dry mass. Both fabric styles incorporate light denier Kevlar-49 yarns, 380 denier for style 181, and 195 denier for style 120.

All of the parts have an outer layer of flame-sprayed aluminum and top-coat applied according to standard production procedures used on the baseline fiberglass parts. The actual savings in component mass achieved by this direct substitution of Kevlar-49 for fiberglass averaged 26 percent for the six parts. Further details on Kevlar-49 part design and fabrication are given in NASA CR-112250 (ref. 1), which is the final report of the fabrication and installation phases of the program.

The first annual inspection results are given in NASA CR-132647 (ref. 2). The Air Canada and TWA panels were inspected at Lockheed in this case due to special circumstances, while Eastern personnel inspected the Eastern panels at Miami.

For the second annual inspection and all subsequent inspections, the program scope was expanded as follows to obtain more complete information and documentation of part conditions:

- A Lockheed Engineering representative is present for each annual inspection at the airlines' maintenance bases.
- Three of the six panels (one of each left-hand and right-hand set) are removed for thorough inspection, weighing, and inspection of fastener holes and interior surface conditions.
- The airlines provide reports to Lockheed on all incidences of damage and repair occurring in service.

The second, third, fourth and fifth annual inspections were conducted in accordance with this expanded scope, and are reported in NASA CR-132733 (ref. 3), NASA CR-145141 (ref. 4), NASA CR-145326 (ref. 5), and NASA CR-159071 (ref. 6).

As discussed in previous reports, the TWA panels were removed after approximately 1 year (2400 hours) of service, and reinstalled on a second TWA L-1011 for continuation of flight service testing. The reinstallation on TWA aircraft N31030 required some rework and repair of the panels,

particularly in the case of the aft engine fairing panels, where relocation of all fastener holes was required. This rework activity is reported in detail in the Second Flight Service Report (ref. 3). The aircraft on which these parts were installed was delivered to TWA in August 1975, and have since been inspected annually in accordance with the expanded program scope.

During 1977, a 5-year extension to the program was received from NASA for a total of 10 years flight service of the Kevlar-49 fairings. This extension carries the program through 1983, and annual inspections of the three ship sets will take place in accordance with the expanded program scope outlined above.

In 1978, Eastern disclosed plans to lease the aircraft with the Kevlar fairings to a foreign carrier, but stated a willingness to reinstall the fairings onto a second aircraft. Additional funding was received for this reinstallation. Removal of the panels took place in 1979 and is discussed in the next Section.

The fairings being evaluated in this program are the earliest Kevlar-49 components placed in commercial airline flight service, predating production applications of Kevlar-49 on commercial transports by several years. These components are exposed to over 2000 flight hours per year of typical aircraft operating environments; and detailed monitoring of the fairings' performance in this program provides information on long-term durability, damage tolerance, chemical resistance, and mechanical properties. Kevlar-49 fibers are the only organic reinforcing fibers used in aircraft structures, and have certain characteristics, such as moisture pickup in the fiber and low resin/fiber bond, which were of concern initially. The resistance of Kevlar-49 composites to long-term service environment as verified by the 6 years of flight service in this program provides confidence in the use of Kevlar-49 for additional aircraft structural applications.

#### PANEL INSPECTIONS

The sixth annual inspection of the Air Canada fairings on Ship CF-TNE-502 (Serial No. 1021) took place on May 25, 1979 at the Montreal Maintenance Base. The right-hand wing-body fairing, the right-hand under-wing fillet, and the left-hand aft engine fairing were removed for inspection, while the opposite set of panels were inspected in place on the aircraft. This was the opposite set to those removed in the previous inspection. The fairings at the date of inspection had been in service for 6 years, and had accumulated 14,580 hours. The interval since the 1978 inspection was only 7 months, and the short interval was due to a revised scheduling of Air Canada's C-checks. The fairings had accumulated 1745 flight hours in that period.

The inspection of the fairings on Eastern Ship N316EA (Serial No. 1022) took place on September 21, 1979 at the Miami Maintenance Base. The aircraft was in for rework prior to delivery to another carrier. As discussed in the previous Section, arrangements were made with Eastern to

reinstall the Kevlar-49 fairings on another aircraft. All six of the fairings were therefore removed and were available for complete inspection. Fiberglass spares had been provided to the three participating airlines when the aircraft were initially delivered, and these were installed on Ship 1022. This took place subsequent to the inspection, and Eastern Maintenance reported that the fiberglass spares were installed without any problems. The fairings had accumulated 17,718 flight hours on Ship 1022 as of the date of their removal, and had been in service 8½ years. The fairings had accumulated 4303 flight hours since their previous inspection in February 1978. Reinstallation of the fairings onto another Eastern L-1011 is scheduled for early 1980.

The fairings installed on TWA Ship N31030 (Serial No. 1111) were inspected at TWA's Los Angeles Maintenance Base on October 21, 1979. The left-hand wing-body fairing, right-hand underwing fillet and right-hand aft engine fairing were removed for inspection while the opposite set was inspected on the aircraft. These were the opposite parts to the wing-body and aft engine fairings removed in the previous inspection. The TWA right-hand underwing fillet, however, is being removed at every inspection through the remainder of the program to obtain accurate mass determinations and detect any indication of continuing moisture pickup. Difficulty has been encountered in obtaining accurate mass determinations of the parts because of the lack of accurate balances at the airline maintenance bases. The proximity of TWA's base to the Lockheed plant makes it feasible to bring in an accurate balance for the inspections. The sandwich panels are too large to weigh on this balance, but the underwing fillet can be readily weighed. This activity was initiated last year on the right-hand part.

The fairings had 10,844 flight hours on Ship 1111 as of the date of inspection. These fairings had been initially installed on Ship 1026, and accumulated 2404 flight hours on that ship prior to removal and reinstallation for a total of 13,248 flight hours. The parts had accumulated 3385 hours in the year since the previous inspection.

Inspection was by visual examination and coin tapping for delaminations and skin-core disbonds. The panels taken off the aircraft were cleaned to remove excessive dirt and residue. These panels were then inspected for the condition of the fastener holes and the inner surface, as well as the outer surface condition which was checked on all six parts.

All three inspections were conducted with the participation of Lockheed Engineering, and with the assistance of airline maintenance personnel in removal and reinstallation of the panels. Photographs were taken of all panels and areas containing defects, damage, or other conditions of special interest. Photographs were provided by Air Canada in Montreal, by the Lockheed Photography Department at TWA in Los Angeles, and by a commercial photographer at Eastern. Detail observations at the three inspections are given in Appendixes A, B, and C.

## DISCUSSION OF INSPECTION RESULTS

The Kevlar-49 panels continue to perform satisfactorily in service with no major damage or defects requiring corrective maintenance. Minor impact damage has occurred, primarily on the wing-body fairing sandwich panels, which are subject to ground handling damage and damage from runway objects. In several instances, the skins have been penetrated exposing the honeycomb. The airlines do not regard this as a serious occurrence as these are lightly loaded nonstructural components which only take aerodynamic loads. Damage is therefore left unrepaired for an indefinite period or else given a cosmetic repair.

The only new incidences of damage noted in the 1979 inspections were a slight gouged area with loose fibers on the Air Canada right-hand wing-body fairing, and a small crack on the TWA left-hand wing-body fairing. These were both on the inner skins and thus were probably caused by the removal and reinstallation procedures. This illustrates the fact that the frequent removal and reinstallation of these test panels increases the likelihood of maintenance damage.

None of the various damage areas noted in previous inspections had propagated or increased in extent, with the possible exception of two inner skin delaminations, one on each of two wing-body fairings, which appear to have increased in area slightly. This lack of damage growth is a significant indication of acceptable damage tolerance for Kevlar-49 in these applications, and in some cases the damage has remained unchanged in appearance or size for four years.

While most of the minor damage observed to date has not been repaired, several repairs have been made to the Kevlar-49 parts, all but one on the exterior wing surfaces of the wing-body fairing sandwich panels. In two instances, cracks have been filled with a resin filler and in one case the filler was coated with conductive paint. One patch consisted of aluminum speed tape with an overcoat of paint, and in another instance a tape overlay appears to have been applied. A patch overlay has also been noted on the inner surface of one of the wing-body fairings. A bolted metal piece has been fastened to the solid laminate edge member of each of the TWA wing-body fairing panels at the same location. This metal piece is associated with a filled fastener hole, but it does not appear to be a patch and its function is not known.

In summary, the repair procedures used on the fairings have been field repairs typical of the procedures used for noncritical fiberglass parts, and adaptable to either line station or maintenance base operations.

The other damage condition which has been typically observed on the Kevlar-49 panels has been fraying and elongation of fastener holes. These have been minor conditions in all instances, which have not required maintenance action or repair. Elongation of the fastener holes has occurred in a random distribution, and has been noted primarily on the underwing fillet panels. This condition is comparable to hole elongation on similar fiber-glass panels which is a fairly common occurrence according to the airlines. The cause of the elongation is concentrated or nonuniform bearing loads possibly resulting from installation problems. There has been relatively little increase in the incidence or severity of this elongation, and in the 1979 inspections no significant increase in elongation was observed over the 1978 results.

The fastener hole fraying appears to be a general occurrence on Kevlar-49 holes and edges where less than optimum machining procedures have been used. The fraying noted on these parts appears to be primarily the result of the initial machining operation, as this condition has remained essentially unchanged with increasing service life. These parts were fabricated in 1972 when development of Kevlar-49 machining techniques was in a very early stage, and the degree of fraying may therefore be more severe than for currently fabricated parts. The removal of both of the Eastern aft engine fairings permitted a direct comparison of fastener hole quality. The holes on the left-hand part were distinctly more frayed than the holes on the right-hand part which tended to be more variable in quality. The difference between these two parts is probably due to variations in machining techniques and operator skills at the time these parts were installed. A similar difference was noted in the degree of fraying on the two solid laminate fillet panels. The elongated holes in the underwing fillets have more fraying than the other holes, indicating that in-service loads can aggravate the initial fraying. There is no evidence that the frayed condition in any way affects part performance.

A different type of damage was initially observed in 1977 on the right-hand TWA wing-body fairing. This was a large teardrop shaped disbond area 11.4 by 2.5 cm (4.5 by 1 inch) in area with an associated deep concave depression indicative of core crushing. The paint and flame spray were intact with no cracks or crazing. This disbond has not increased in area or depth since the 1977 inspection. A similar but smaller disbonded and depressed area was initially observed in 1976, and has not grown since the 1977 inspection. These occurrences, which are unique to this particular fairing, are probably related to a repair made when the part was reinstalled on Ship 1111 (ref.3). This repair was not documented, but apparently consisted of replacement of a damaged core area, extending partially through the core thickness, with a microballoon-filled potting compound. This is not therefore a Kevlar-49-related problem, but as it is a highly visible condition it will be monitored in future inspections.

The Kevlar-49 parts have not been affected to any discernible degree by exposure to Skydrol or other aircraft fluids, although the wing fairings and

fillets are adjacent to hydraulic lines. The aft engine fairings also are exposed to Skydrol, which appears to have attacked a vapor barrier coating on some of the parts. Paint adhesion to the Kevlar-49 surfaces appears to be comparable to fiberglass parts, as would be expected.

The Kevlar-49 parts have been weighed on the occasions when they have been removed. The effects of paint loss, repainting, resealing, and repair have masked any mass change due to moisture pickup; and determination of mass changes has been hampered by the lack of suitable balances at the airline maintenance bases. A balance has been brought from Lockheed to the TWA base in Los Angeles for weighing of the small underwing fillet panel in the last two inspections. Accurate mass determinations have been obtained on the right-hand fillet (Appendix C), and the mass of this part will be monitored throughout the remainder of the program.

#### SUMMARY OF RESULTS AND CONCLUSIONS

The Kevlar-49 fairing panels continue to perform satisfactorily and are free of major damage or defects after 6 years of service and a total of 45,000 flight hours on the three aircraft.

Two types of minor damage have been noted: cracks resulting from impact observed principally on the wing-body fairings; and fraying and elongation of fastener holes. The cracks are primarily the result of ground handling damage, while the fastener hole fraying and elongation appears to be primarily the result of the initial drilling and installation procedures, aggravated in a few instances by in-service loads. The absence of crack growth or significantly increased hole elongation, and the random limited occurrence of the hole elongation indicates that Kevlar-49 is resistant to damage propagation under the relatively light loading conditions typical of fairings. The fastener hole fraying is the only damage condition observed on the Kevlar-49 parts which is not also typical of similar fiberglass parts. The fraying has not increased in severity with increasing service life, and does not have any apparent effect on part performance.

The Kevlar-49 panels have been free of delaminations, and only a few minor skin-core disbonds have occurred. No defects have been observed which can be attributed to moisture or other environmental factors. These findings indicate that two properties of Kevlar-49 which have been of concern - the poor resin-fiber interface bond and the moisture pickup of the Kevlar-49 fibers - have not seriously affected part performance.

In summary, Kevlar-49/epoxy appears to provide service life and structural performance for lightly loaded secondary structures equivalent to that of fiberglass/epoxy.

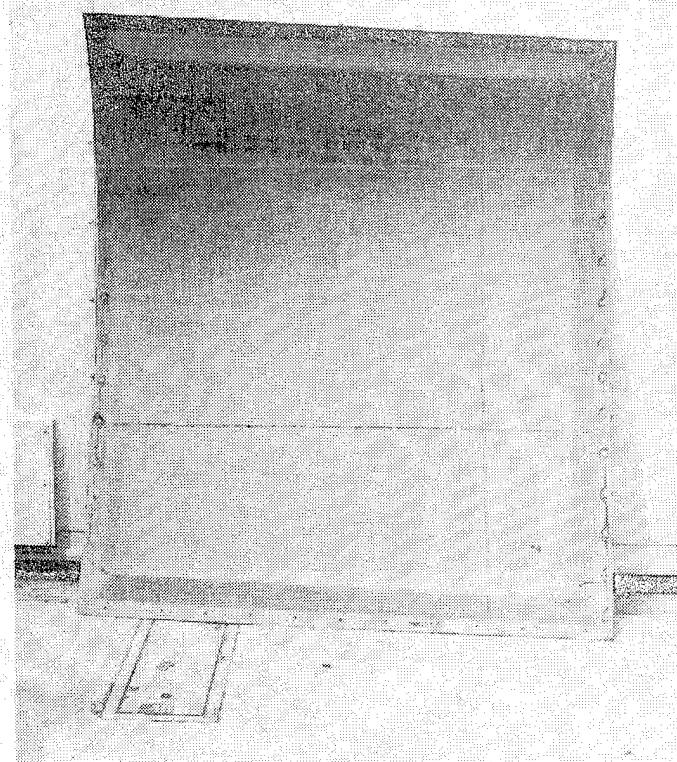


Figure 1. - Right-hand wing-body fairing-inner surface.

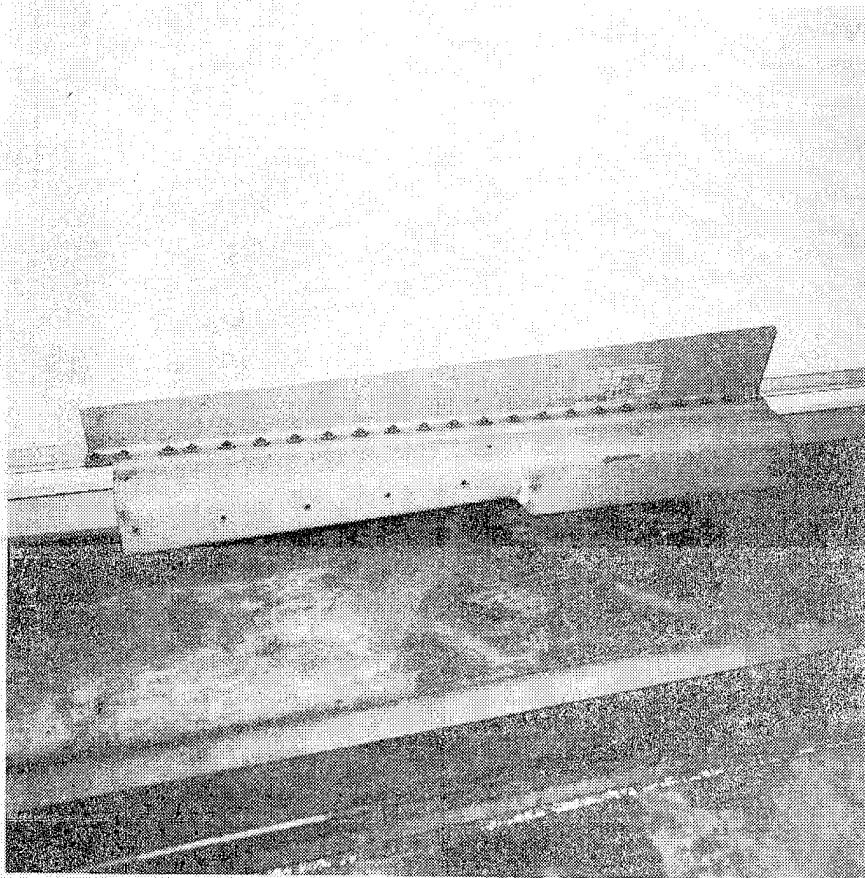


Figure 2. - Right-hand under-wing fillet-inner surface.

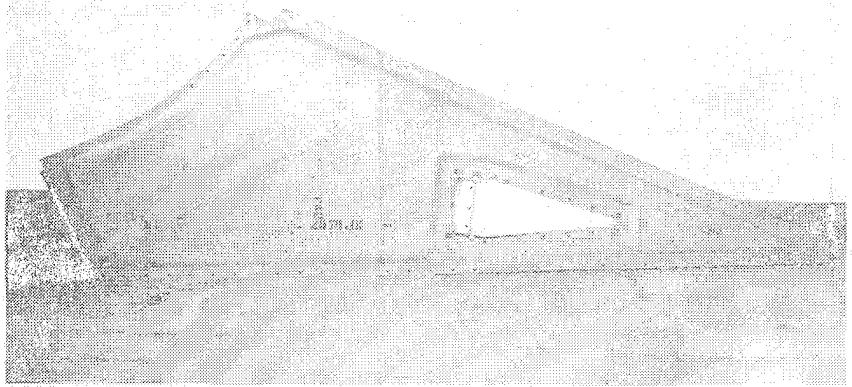


Figure 3.1 - left-hand aft engine fairing-inner surface.

APPENDIX A  
DETAIL OBSERVATIONS OF  
KEVLAR-49 FAIRING PANELS -  
AIR CANADA SHIP CF-TNB-502 (SERIAL 1021) -

MAY 1979

Three of the six fairing panels were removed for inspection: the right-hand wing-body fairing and underwing fillet panels, and the left-hand aft engine fairing. The other panels were inspected in place on the aircraft. No mass determinations were obtained at this inspection.

RIGHT-HAND WING-BODY FAIRING

1. Two exterior surface cracks observed in earlier inspections had not propagated or changed in appearance. These were a 0.3 cm (1/8 inch) crack in the center area first observed in 1976, and a 0.6 cm (1/4 inch) crack in the forward center first observed in 1975.
2. Three delaminated areas on the inner skin previously observed in 1977 were noted as follows:
  - An area in the upper center of the panel 12.7 by 0.6-1.3 cm (5 in by  $\frac{1}{4}$ - $\frac{1}{2}$  in.) had not significantly increased in area. (Figure 4)
  - Another delaminated area close to this first area, had increased in area from 2.5 by 1.3 cm. (1 by  $\frac{1}{2}$  inch) to 2.5 by 2.2 cm (1 by 7/8 inch). (Figure 4)
  - A third delamination in the lower aft panel area 10.2 by 1.3-2.2 cm (4 by  $\frac{1}{2}$  - 7/8 in.) was unchanged in area.

3. An area 26.7 cm (10½ in.) by 3.2 cm (1¼ in.) slightly below the two upper delaminations was first observed in 1977 to have an overlay, presumably a repair patch, which had been sanded. (Figure 4). This area was unchanged in appearance. There was no associated delamination.
4. A gouged area with loose fibers was noted on the lower forward area of the inner surface. (Figure 5). This condition had not been observed previously.
5. Slight fraying was observed on all fastener holes on the top, forward, and aft edges. A greater degree of fraying was observed on the holes on the lower edge. (Figure 6). For comparison, a fastener hole from a similar fiberglass fairing is shown in Figure 7.
6. Several holes on the lower edge were elongated. No holes on the other edges were elongated. Fastener mark-off was observed on the inner surface around all holes on the lower edge. (Figure 8).

#### RIGHT-HAND UNDERWING FILLET

1. No surface damage or defects were noted on either surface although there was considerable paint loss with exposed Kevlar-49. (Figure 9). The location of the exposed Kevlar-49 is such that very little ultraviolet exposure can occur.
2. Fraying was noted on most of the fastener holes, (Figure 10), with four holes more frayed than the others. About half the holes had a significant degree of elongation, with seven holes elongated to 0.55 cm (7/32 in.) maximum dimension from the original 0.5 cm (3/16 in.) diameter, and two holes elongated to 0.6 cm (1/4 in.). There was no correlation between the frayed and elongated holes.

#### LEFT-HAND AFT ENGINE FAIRING

1. No damage, delamination, or disbond was observed on either surface.
2. All of the fastener holes were heavily frayed. (Figure 11). A small number of holes were elongated: four holes to a maximum 0.55 cm (7/32 in.) dimension from the original 0.5 cm (3/16 in.) diameter, and four holes to a maximum 0.6 cm (1/4 in.) dimension.

#### LEFT-HAND WING-BODY FAIRING

1. No new incidences of damage were observed on the exterior surface. Several damage areas observed in earlier inspection had not increased in area or extent. These included a deep gouge in the upper center area 0.4 by 0.6 cm (5/32 by  $\frac{1}{4}$  in.) with delamination extending 0.3 (1/8 in.) around the gouge; and a gouged area on the lower forward edge, both observed initially in 1978.
2. A repaired area was unchanged in appearance with no associated delamination. This was the repair of a 3.2 cm (1 $\frac{1}{4}$  in.) crack in the upper aft area of the exterior surface which had been originally observed in 1974. This repair, which consisted of a resin filler applied into the crack area followed by a coating of conductive paint, had been performed between the 1977 and 1978 inspections.

#### LEFT-HAND UNDERWING FILLET

1. No exterior surface damage was observed, although there was extensive paint loss with exposed Kevlar-49 in the upper area. No fastener gap or misalignment was observed.

#### RIGHT-HAND AFT ENGINE FAIRING

1. No exterior surface damage was observed. This part has had extensive paint blistering since installation, but there is no exposed Kevlar-49 surface area.

#### FIBERGLASS FAIRING

A fiberglass wing-body fairing had been removed and was available for inspection. For comparison, a typical fastener hole is shown in Figure 7. No damage or hole elongation was observed on this panel.

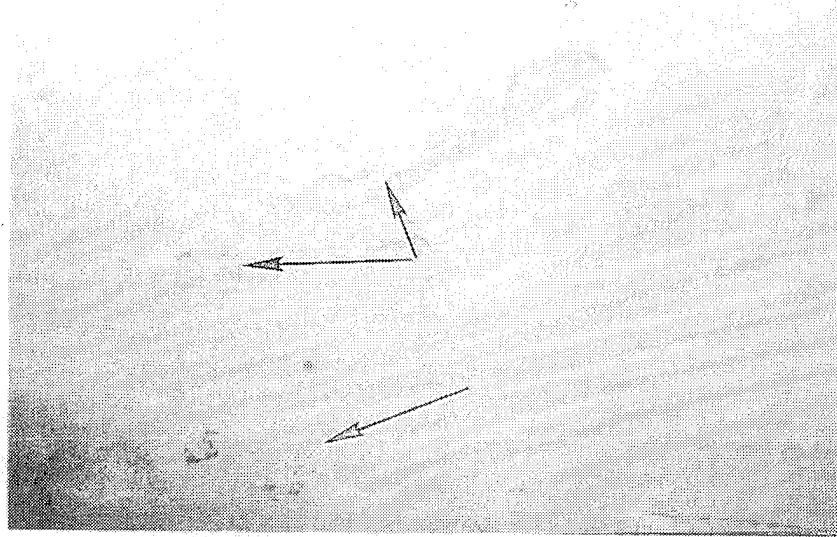


Figure 4. - Air Canada right-hand wing-body fairing showing outlined areas of delamination and overlay patch on inner surface.

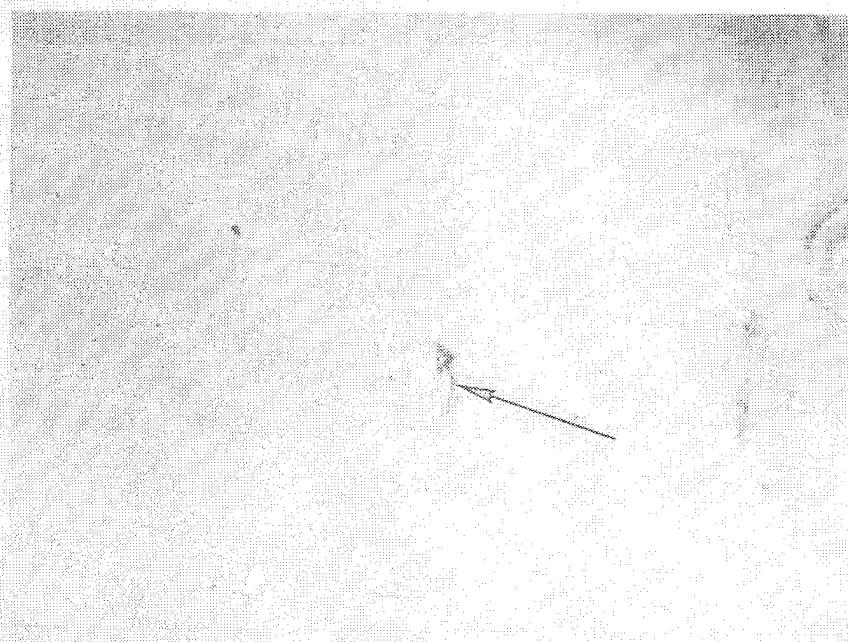


Figure 5. - Air Canada right-hand wing-body fairing-gouged area with loose fibers on inner surface.

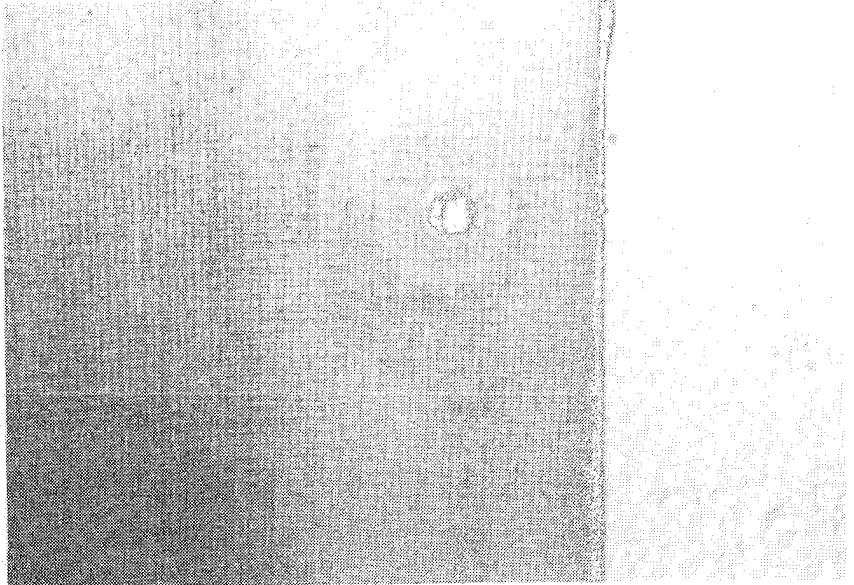


Figure 6. - Air Canada right-hand wing-body fairing - typical fastener hole.

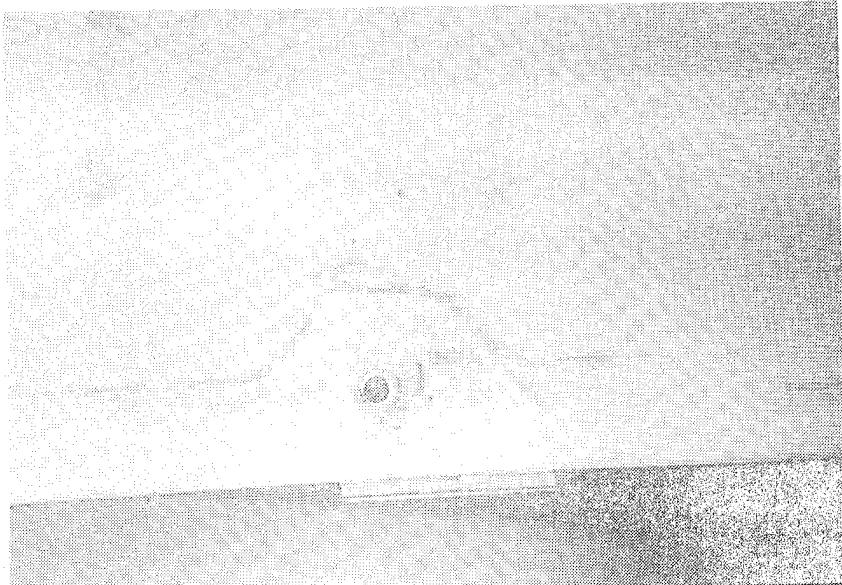


Figure 7. - Air Canada fiberglass wing-body fairing - typical fastener hole.



Figure 8. - Air Canada right-hand wing-body fairing - fastener hole on lower edge with mark-off.



Figure 9. - Air Canada right-hand underwing fillet - exterior surface showing paint loss and exposed Kevlar-49.

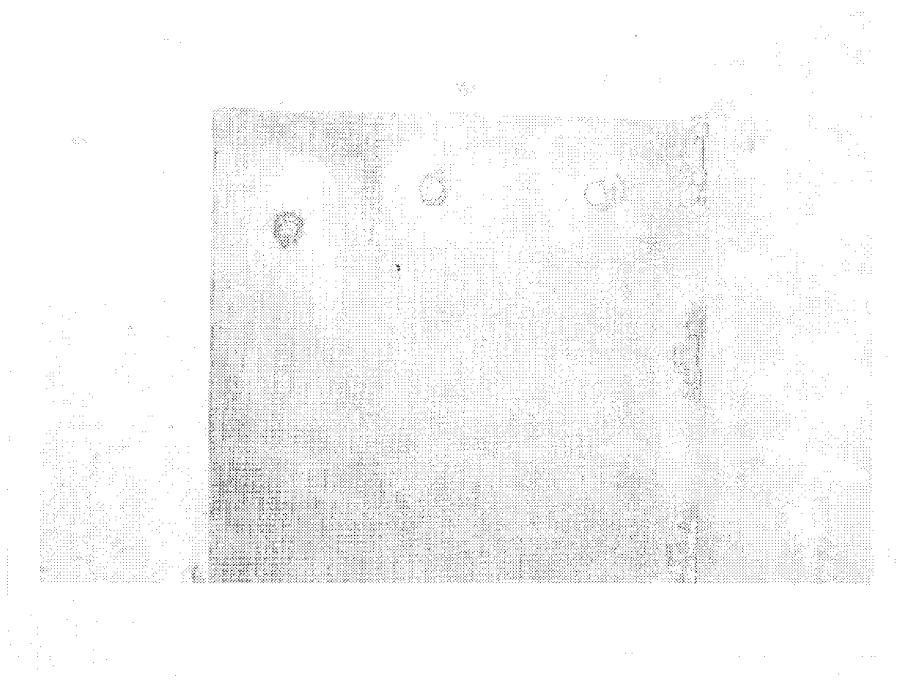


Figure 10. - Air Canada right-hand underwing fillet - fastener holes with frayed condition.

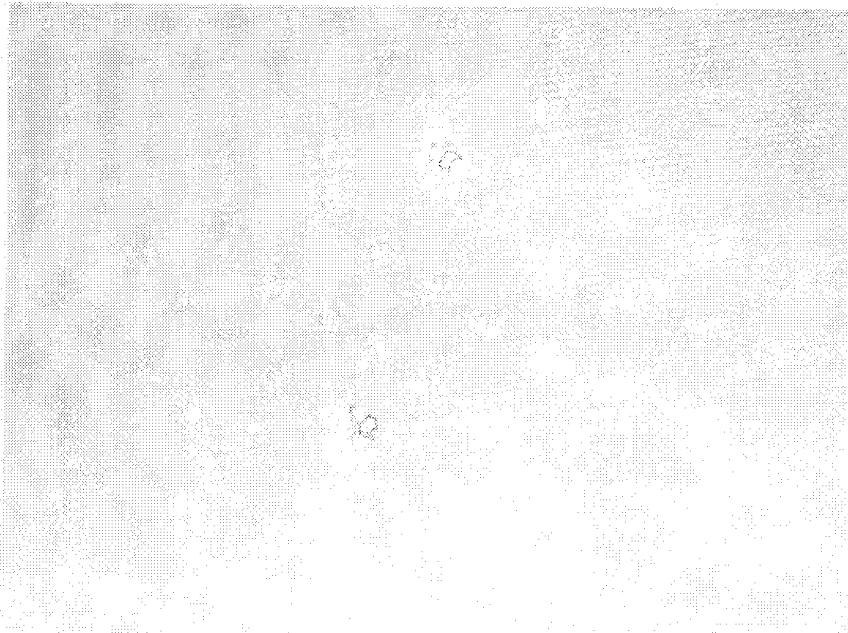


Figure 11. - Air Canada left-hand aft engine fairing - fastener holes in core area showing frayed condition.

APPENDIX B  
DETAIL OBSERVATIONS OF  
KEVLAR-49 FAIRING PANELS -  
EASTERN SHIP N314EA (SERIAL 1022) -  
SEPTEMBER 1979

All six of the Kevlar-49 fairings were removed in preparation for the reinstallation onto another aircraft and were available for complete inspection. No mass determinations were obtained due to the unavailability of a suitable balance.

LEFT-HAND WING-BODY FAIRING

1. A deep gouge and associated crack 2.5 cm (1 in.) in length in the upper forward area of the exterior surface was observed in 1978. This had been filled with a thixotropic resin filler forming a triangular patch approximately  $12.9 \text{ cm}^2$  (2 in.<sup>2</sup>) in area.
2. A speed tape patch first observed in 1975 had more area torn off partially exposing the original crack to a length of 1.6 cm (5/8 in.). (Figure 12). There was still no associated delamination.
3. An area of flame spray loss in the lower aft area which exposed the Kevlar-49 surface had been repainted. This condition had been noted in 1977, so the Kevlar-49 surface may have had 2 years exposure to ultraviolet. A delaminated area 3.8 by 2.5 cm (1½ by 1 in.) was located within the repainted area. This had not been observed previously, and may have been a filled crack.
4. A delaminated area 3.2 by 2.5 cm (1¼ by 1 in.) on the inner surface with a delaminated strip 15.2 by 1.3-1.6 cm (6 by ½ - 5/8 in.) extending from it appears to be increasing slightly in area. In 1975 the delamination was 1.3 cm (½ in. diameter), while in 1977 the area was 1.9 cm (3/4 in. diameter). The 15.2 cm (6 in.) strip has not increased in area, however.

5. Slight fraying was observed on all the fastener holes. All holes on the lower edges had slight elongation and noticeable mark-off of the washers, with a convex deformation of the laminate around the holes. (Figure 13). Several holes on the other edges were slightly elongated. Two holes on the top edge at the forward end were badly frayed and elongated to a 0.6 cm ( $\frac{1}{4}$  in.) maximum dimension. (Figure 14).

#### RIGHT-HAND WING-BODY FAIRING

1. Several exterior surface cracks observed in previous inspections had not propagated or changed in appearance:
  - A 1.3 cm ( $\frac{1}{2}$  in.) crack in the forward edge between the fifth and sixth holes from the top. (Figure 15).
  - A 0.3 cm (1/8 in.) ding in the lower center area.
  - A 0.3 cm (1/8 in.) crack in the aft center area.
  - A 0.8 cm (5/16 in.) crack in the lower forward area. (Figure 16).
  - A 0.8 cm (5/16 in.) crack in the upper forward area which may be only in the paint.
  - A 0.6 cm (1/4 in.) crack in the center which appears more definitely now to be only in the paint.
2. A slight disbond area in the upper aft area of the inner surface, first observed in 1976, had not changed in appearance or extent. This area was 1.3 by 0.6 cm ( $\frac{1}{2}$  in. by  $\frac{1}{4}$  in.), and was adjacent to a vertical line 38 cm (15 in.) from the aft edge which was slightly depressed and which corresponded to a similar line on the exterior face. This appears to be the location of a core splice. There are two similar horizontal lines, but no delaminations are associated with these.
3. The fastener holes all showed a slight degree of fraying, with the holes on the lower edge more frayed than the others. Twelve holes located on all the edges were slightly elongated, but only one hole of the aft edge was significantly elongated to 0.6 cm ( $\frac{1}{4}$  in.). The holes on the lower edge showed mark-off of the washers on the inner surface with a convex deformation around the holes.

#### LEFT-HAND UNDER-WING FILLET

1. No defects or damage was noted on the outer surface except for extensive paint loss with some exposed Kevlar-49 surface. A slight gouged spot on the inner surface, observed in previous inspections, was unchanged in appearance with no associated delamination.
2. All fastener holes were frayed to a greater extent than observed on the wing-body fairings, with several holes frayed noticeably more than the others. (Figure 17). Slight elongation was observed on several holes (Figure 17) with two holes significantly elongated to 0.55 cm (7/32 in.) from the original 0.5 cm (3/16 in.) diameter. There was no definite correlation between fraying and elongation.

#### RIGHT-HAND UNDER-WING FILLET

1. No damage or defects were noted on either surface except for the paint loss which left some exposed Kevlar-49 surface in the upper area.
2. All fastener holes were frayed, but to a lesser degree than the left-hand fillet described above. Several holes were more frayed than the others. (Figure 18). Three holes were slightly elongated; while three holes were significantly elongated, two to 0.55 cm (7/32 in.) and one to 0.6 cm (1/4 in.). In this case, the elongated holes were more frayed than the other holes.

#### LEFT-HAND AFT ENGINE FAIRING

1. No damage or defects were noted on the inner surface, but there was loss of paint and flame spray in two exterior surface areas with the Kevlar-49 surface exposed to ultraviolet. (Figure 19). These areas were relatively small, with the largest 15 cm (6 in.) diameter in the upper aft corner area. There was a slight associated abrasion in the center of this area with a few exposed Kevlar-49 fibers. This part had been inspected by Eastern Maintenance in 1977 and a puncture in this area covered by tape was observed at that time. This abrasion appears to be the same as the previously reported puncture, but there was no longer any tape, and any full skin penetration had been filled in some manner and repainted. In 1978, the

paint was still intact in that area preventing any observation of this defect.

2. Fraying was observed on all fastener holes. This fraying was more severe than on the wing-body fairing and under-wing fillet panels. (Figure 20). The intercostal holes were less frayed than the holes in the solid laminate edge member. Slight elongation was observed on about 10% of the holes.

#### RIGHT-HAND AFT ENGINE FAIRING

1. No damage or defects were noted on either surface, but there was some loss of paint and flame spray with exposed Kevlar-49.
2. Fraying was observed on all fastener holes with relatively slight fraying on the aft edges and greater fraying on the upper and lower edges. The intercostal holes were also frayed except for the forward intercostal. (Figure 21). Fraying was generally less severe and more variable than on the left-hand part. Several holes on the lower edge had a slight elongation. Four holes on the center intercostal were significantly elongated, one to maximum dimension of 0.6 cm ( $\frac{1}{4}$  in.), one to 0.55 cm (7/32 in.) dimension, and two others to 0.95 cm (3/8 in.) from the original 0.5 cm (3/16 in.) diameter.

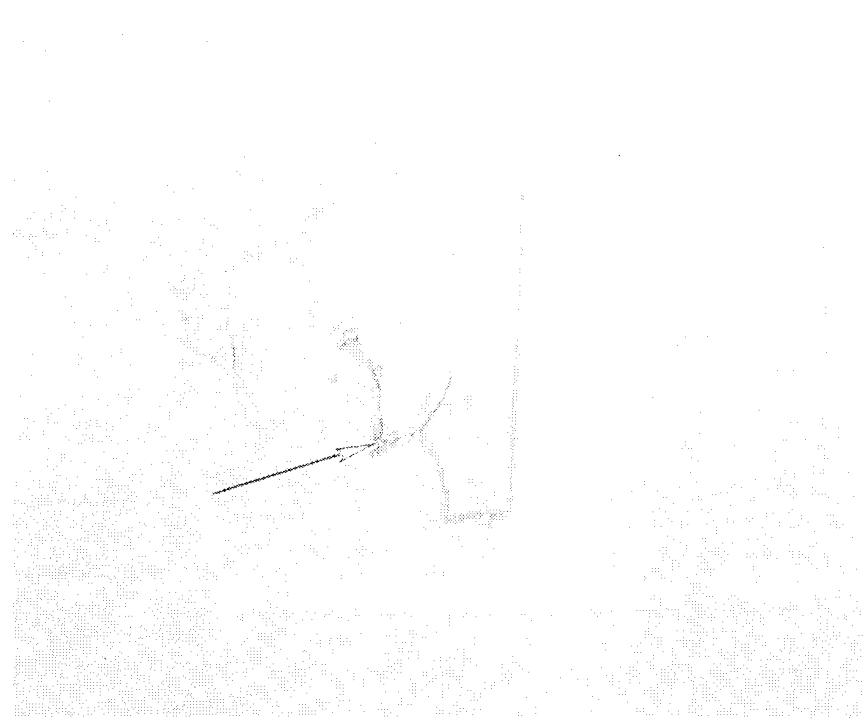


Figure 12. - Eastern left-hand wing-body fairing - speed tape patch with exposed crack.

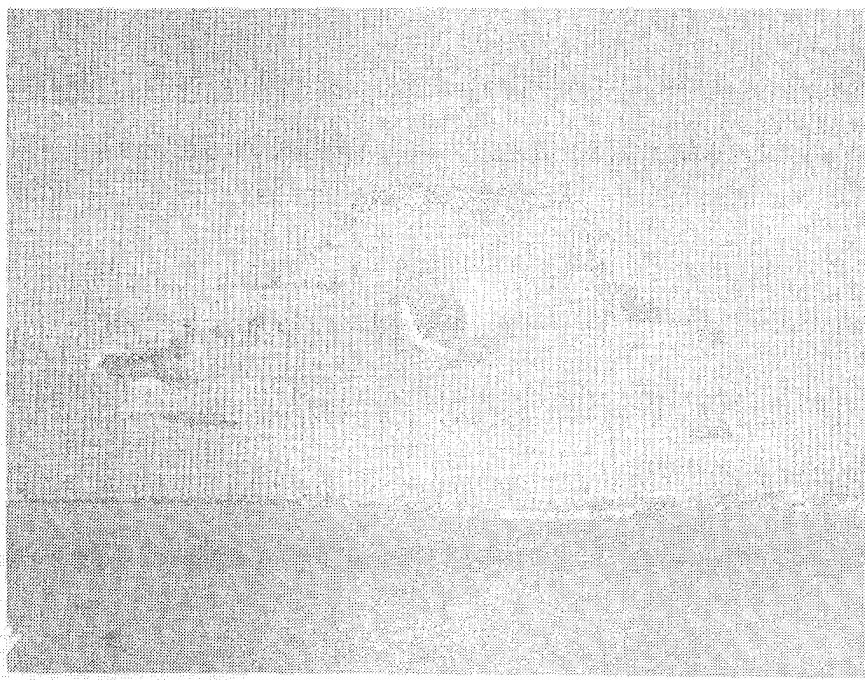


Figure 13. - Eastern left-hand wing-body fairing - fastener hole on lower edge with mark-off.

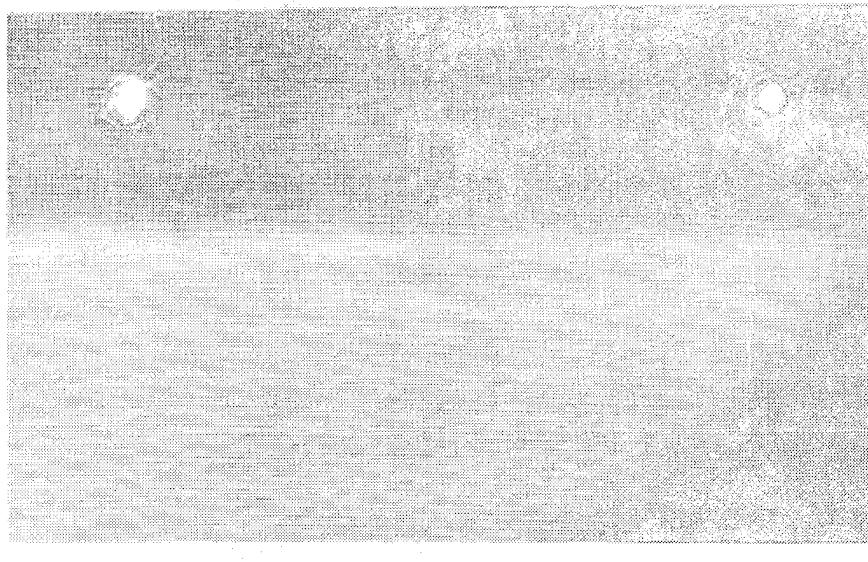


Figure 14. - Eastern left-hand wing-body fairing - frayed and elongated holes on top edge.

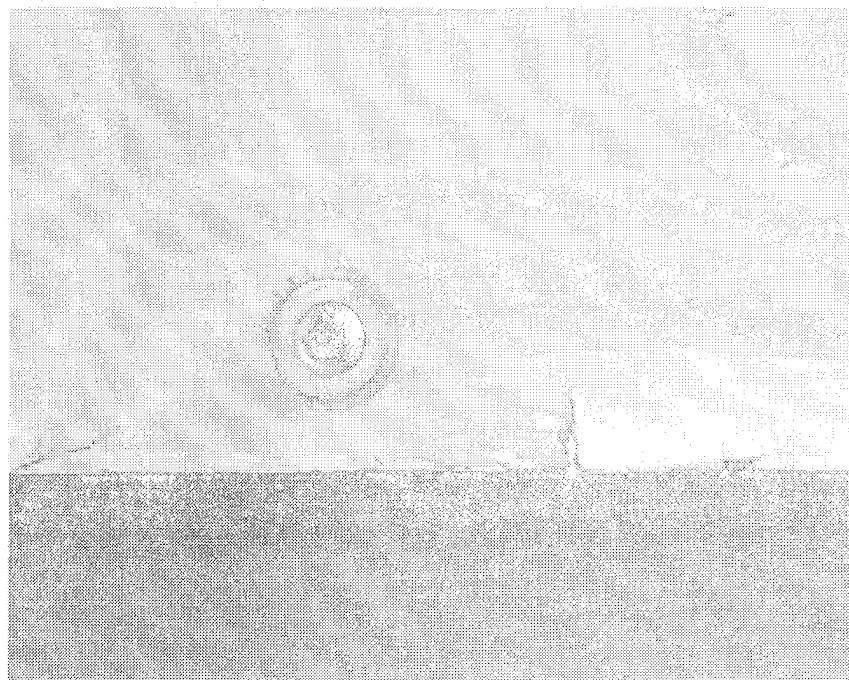


Figure 15. - Eastern right-hand wing-body fairing - crack in forward edge.

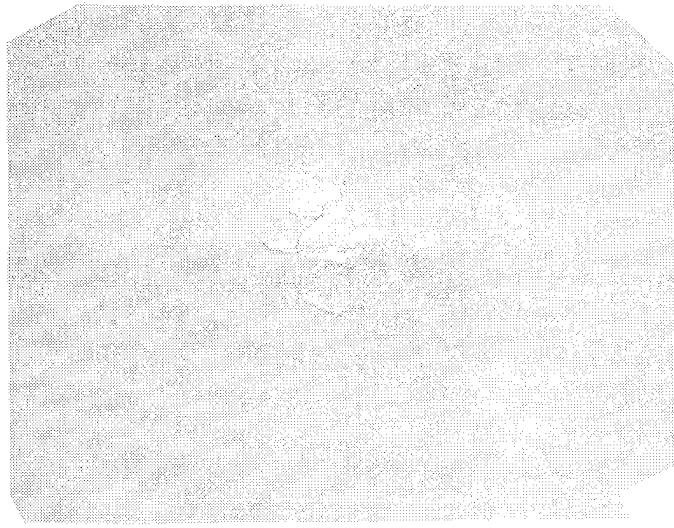


Figure 16. - Eastern right-hand wing-body fairing -  
0.8 cm (5/16 in.) crack on exterior surface.

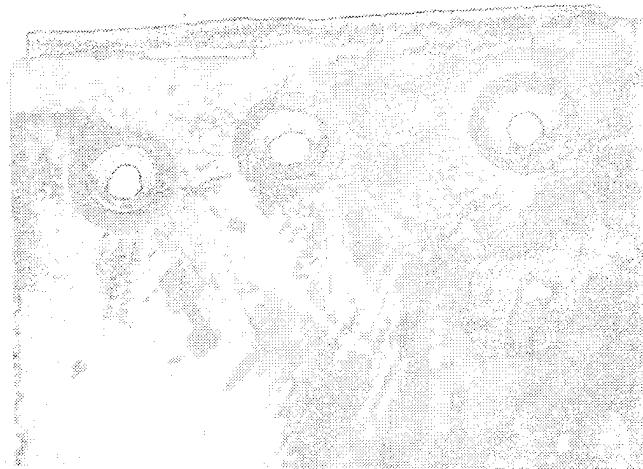


Figure 17. - Eastern left-hand underwing fillet - frayed  
and elongated fastener holes from exterior.

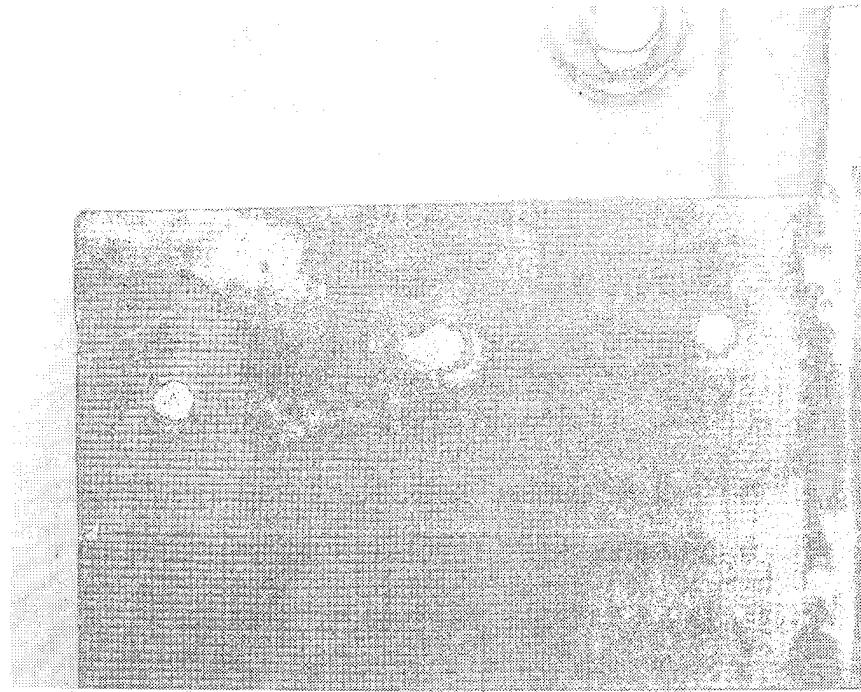


Figure 18. - Eastern right-hand underwing fillet - frayed  
and elongated holes from inner surface.

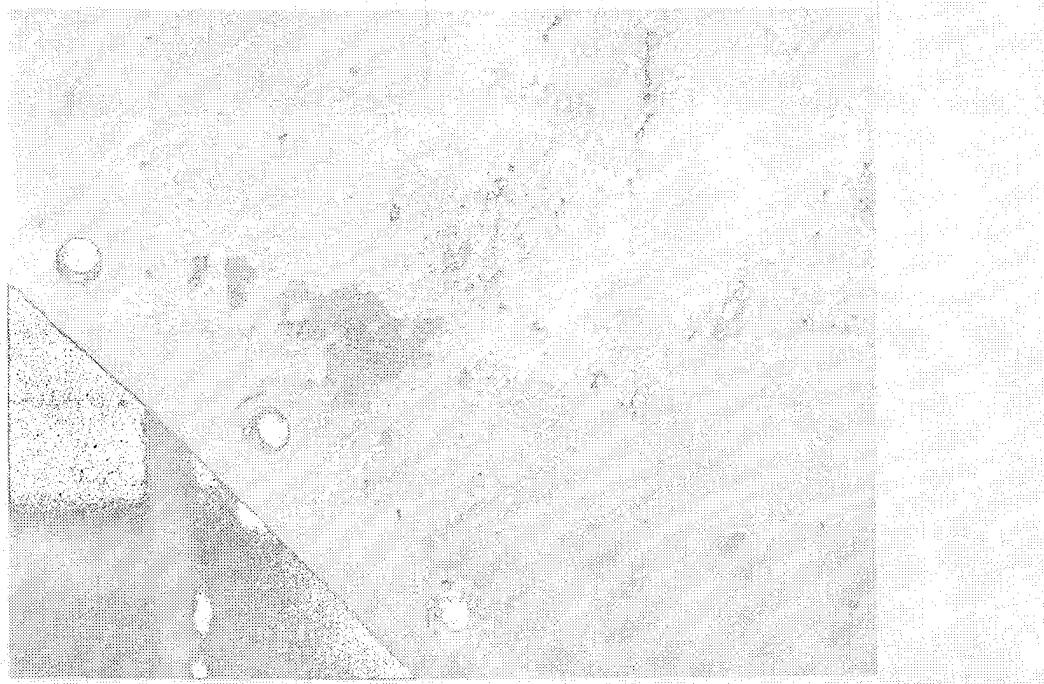


Figure 19. - Eastern left-hand aft engine fairing - paint and flame  
spray loss with exposed Kevlar-49 laminate.

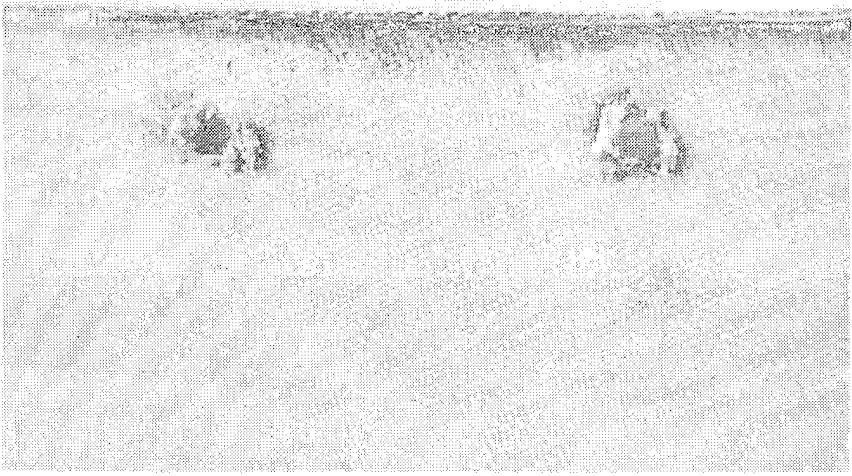


Figure 20. - Eastern left-hand aft engine fairing - fastener holes with severe fraying.

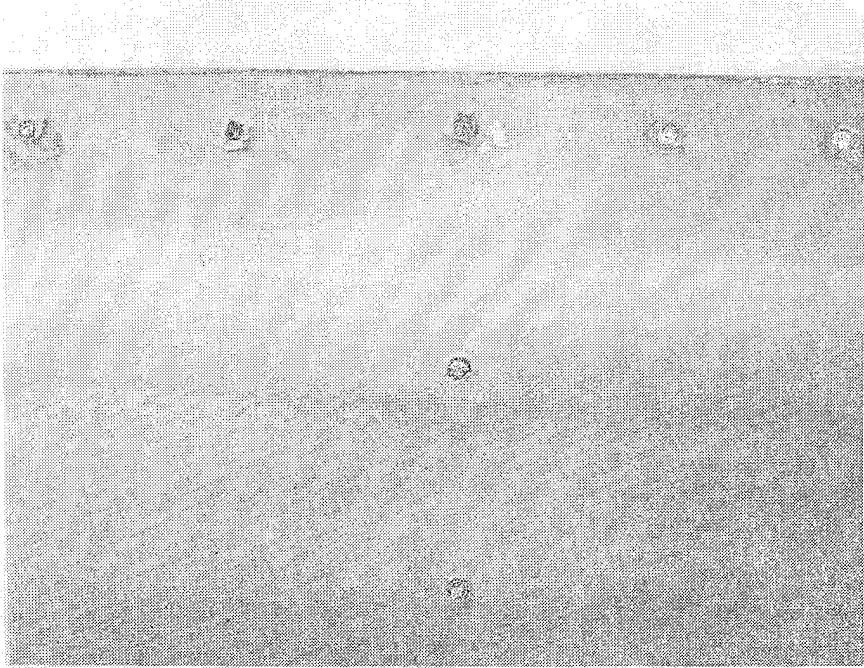


Figure 21. - Eastern right-hand aft engine fairing - fastener holes with moderate fraying.

APPENDIX C  
DETAIL OBSERVATION OF  
KEVLAR-49 FAIRING PANELS -  
TWA SHIP N31030 (SERIAL 1111)  
OCTOBER 1979

Three of the six fairing panels were removed for inspection: the left-hand wing-body fairing, the right-hand underwing fillet, and the right-hand aft engine fairing. The other panels were inspected in place on the aircraft. The underwing fillet panel was weighed using an accurate balance brought from the Lockheed plant.

LEFT-HAND WING-BODY FAIRING

1. Two exterior surface defects observed in previous inspections had not increased in area. These were a deep gouge 1.3 cm ( $\frac{1}{2}$  in.) length in the upper forward area (Figure 22) with a disbond area extending forward of the gouge in a 1.3 cm ( $\frac{1}{2}$  in.) radius arc; and a small 0.3 cm (1/8 in.) crack in the upper aft area, which had been painted over in the previous inspection. The crack was first observed in 1977, and the gouge was first observed in 1978.
2. The inner surface had a crescent-shaped crack 0.5 cm (3/16 in.) in length, with an associated delaminated area. This crack was in the lower forward area.
3. Slight fraying was observed on most fastener holes on the upper and forward edges. The holes on the aft and lower edges were more heavily frayed. Three holes on the forward edge were heavily frayed and were also elongated - two holes to a 0.6 cm ( $\frac{1}{4}$  in.) dimension and one to a 0.55 cm (7/32 in.) dimension. No other elongated holes were noted.
4. A bolted metal attachment covering a filled fastener hole was observed on the lower edge between the two aft holes. (Figures 23 and 24). When the panels were reinstalled, there was no record of hole relocation on the left-hand fairing.

(Reference 3) so the origin of this filled hole is uncertain. The metal piece is not flat and does not appear to be a patch. Its function could not be determined at the time of the inspection, but it could have been for drainage with the drain hole subsequently filled, or it could be part of a latch arrangement.

#### RIGHT-HAND UNDER-WING FILLET

1. The panel mass was 664.6 gm. (1.465 lb.). The previous mass obtained in the 1978 inspection (also with a balance brought from Lockheed) was 663.75 gm. (1.463 lb.).
2. There was no surface damage or defects on either surface.
3. Heavy fraying was visible on about 2/3 of the fastener holes, (Figure 25) with the remaining showing slight fraying. Four holes, all badly frayed, had significant elongation; three of these to a maximum 0.55 cm (7/32 in.) dimension and one to a 0.6 cm (1/4 in.) dimension. One fastener hole had been filled and relocated on this part at the time of the reinstallation, and there was no observable defect associated with the filled area.

#### RIGHT-HAND AFT ENGINE FAIRING

1. There was no damage to either surface. Loss of paint and flame spray had left some exposed Kevlar-49 surface. The vapor barrier coating, which had been applied to the inner surface during reinstallation to replace the Tedlar film, had been chemically attacked in several areas, probably by Skydrol. (Figure 26).
2. There was no fastener hole fraying (Figure 27). All holes had been relocated at the time of reinstallation, and a surface layer of resin impregnated 120 fiberglass fabric had been bonded to both surfaces prior to drilling the relocated holes.
3. There were a significant number of elongated holes (Figure 27). Ten holes were elongated to 0.55 cm (7/32 in.) from the original 0.5 cm (3/16 in.) diameter; 17 holes were elongated to 0.6 cm (1/4 in.); and two holes were elongated to 0.95 cm (3/8 in.). Three intercostal holes were also elongated to 0.55 cm (7/32 in.). These elongated holes constituted about 30% of total. Since all holes were relocated, it appears probable that the filled hole areas accounted for the high incidence of elongation.

#### RIGHT-HAND WING-BODY FAIRING

1. A large teardrop-shaped disbond and crushed area 11.4 by 2.5 cm (4½ by 1 inch) first observed in 1977, was unchanged in appearance or extent. (Figure 28). This was in the lower forward area of the exterior surface. Another delamination in the lower forward area 5.1 by 1.3 cm (2 by ½ in.) first observed in 1976 had not increased in area since the 1977 inspection. A small crack 0.3 cm (1/8 in.) also had not increased in length since first observed in 1976. No other damage was noted.
2. A bolted metal attachment of the same type and in the same location as the one on the left-hand part was noted. This was the location of two relocated holes which were filled with resin at the time the panel was reinstalled, but the metal attachment does not appear to be related to these relocated holes.
3. A rectangular patch overlay 10 by 20 cm (4 by 8 in.) was noted on the forward edge in the lower exterior surface area. This patch was first observed in 1978 to be 30.5 by 13 cm (12 in. by 5 in.) in area. It appears to be merely a tape overlay and thus could readily have been reworked or replaced.

#### LEFT-HAND UNDERWING FILLET

1. No damage or defects were detected on the exterior surface.

#### LEFT-HAND AFT ENGINE FAIRING

1. No damage or defects were detected on the exterior surface, except for two paint loss areas one of which left an exposed Kevlar-49 surface area.

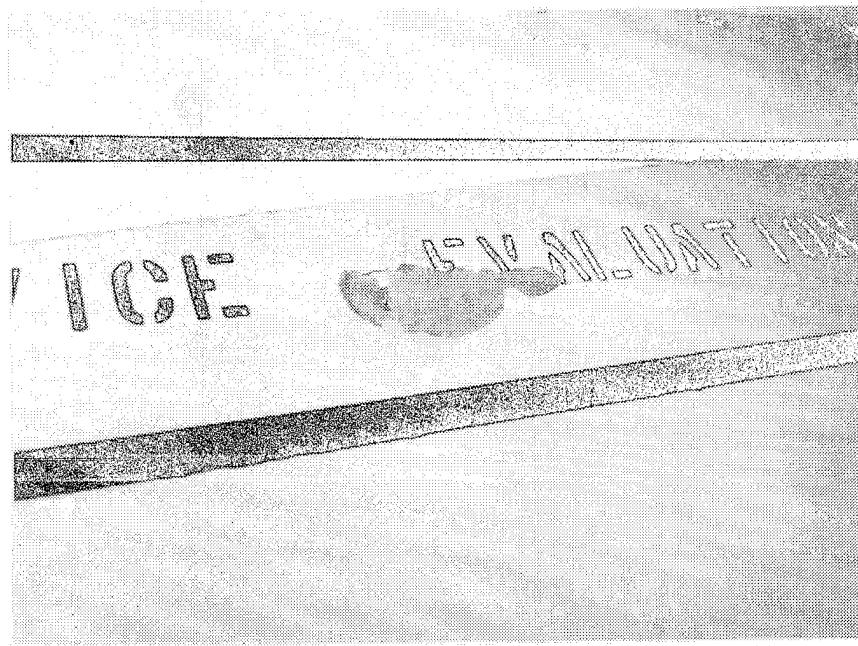


Figure 22. - TWA left-hand wing-body fairing - 1.3 cm ( $\frac{1}{2}$  in) crack on exterior surface.

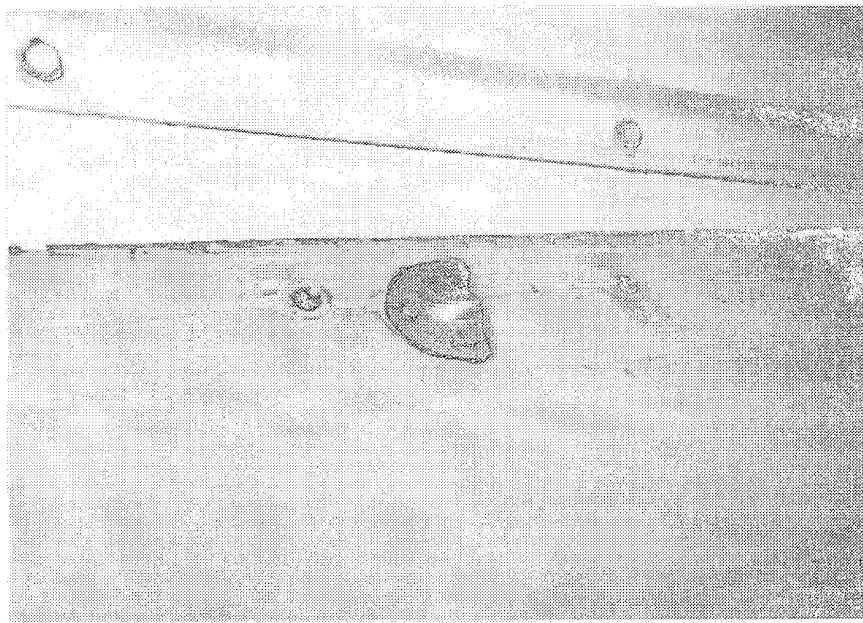


Figure 23. - TWA left-hand wing-body fairing - metal attachment from exterior.

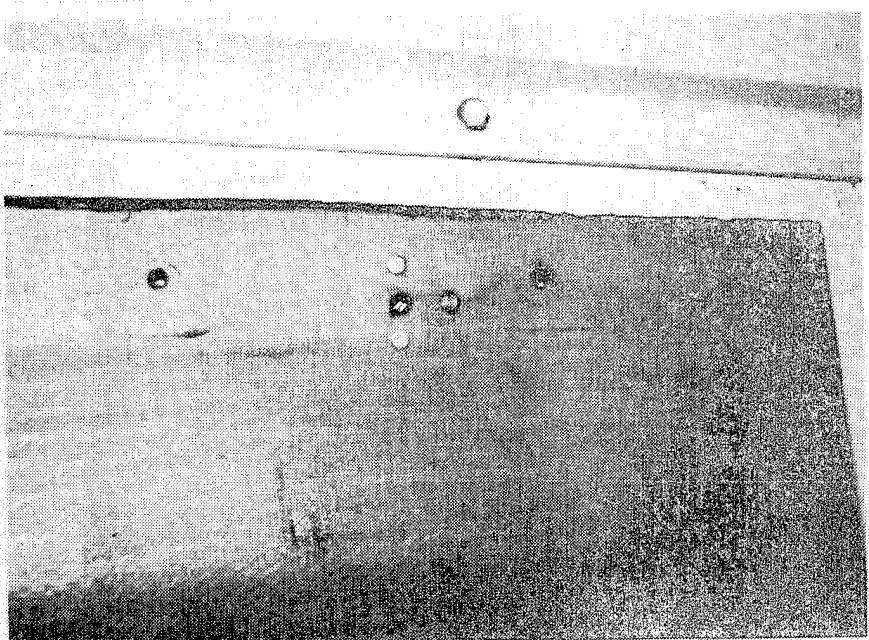


Figure 24. - TWA left-hand wing-body fairing -  
metal attachment from interior.

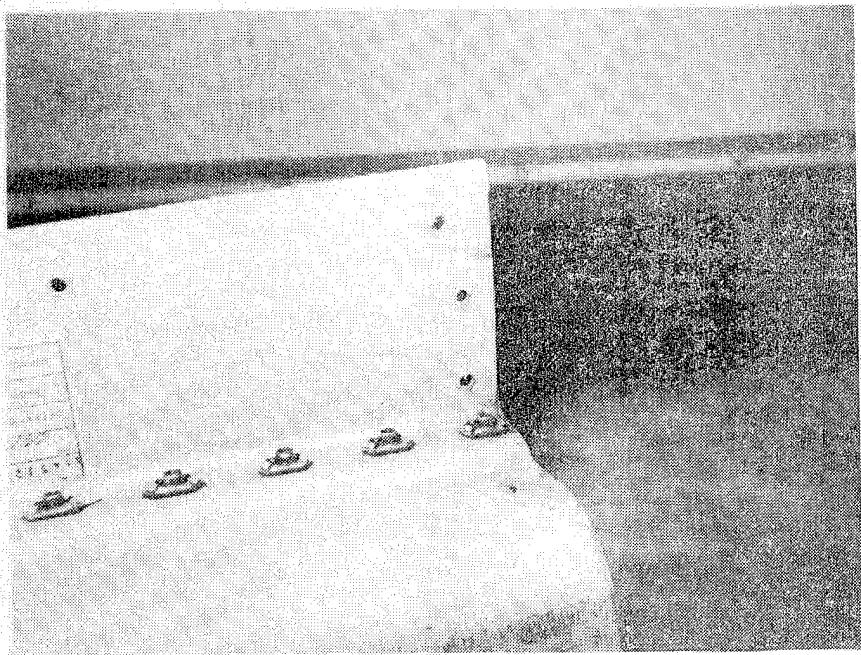


Figure 25. - TWA right-hand underwing fillet - fastener  
holes with frayed condition.

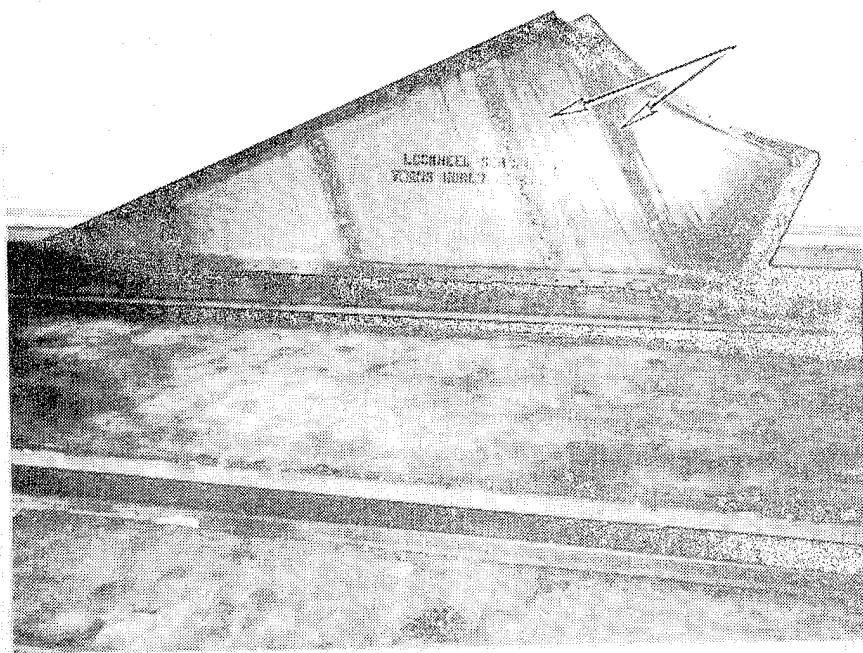


Figure 26. - TWA right-hand aft engine fairing - inner surface with vapor barrier coating showing chemical attack.

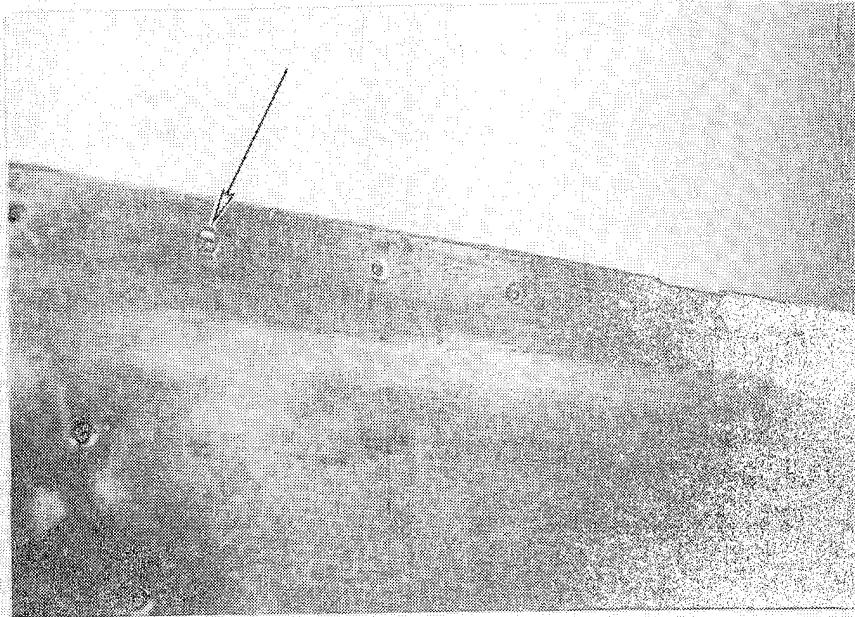


Figure 27. - TWA right-hand aft engine fairing - showing unfrayed fastener holes and an elongated hole.



Figure 28. - TWA right-hand wing-body fairing - disbonded and crushed area on exterior.

#### REFERENCES

1. Wooley, J. H.; Paschal, D. R.; and Crilly, E. R.: Flight Service Evaluation of PRD-49/Epoxy Composite Panels in Wide-Bodied Commercial Transport Aircraft - Final Report, NASA CR-112250, March 1973.
2. Wooley, J. H.; Flight Service Evaluation of PRD-49/Epoxy Composite Panels in Wide-Bodied Commercial Transport Aircraft - First Annual Flight Service Report. NASA CR-132647, July 1974.
3. Stone, R. H.; Flight Service Evaluation of Kevlar-49/Epoxy Composite Panels in Wide-Bodied Commercial Transport Aircraft - Second Annual Flight Service Report. NASA CR-132733, October 1975.
4. Stone, R. H.; Flight Service Evaluation of Kevlar-49/Epoxy Composite Panels in Wide-Bodied Commercial Transport Aircraft - Third Annual Flight Service Report. NASA CR-145141, March 1977.
5. Stone, R. H.; Flight Service Evaluation of Kevlar-49/Epoxy Composite Panels in Wide-Bodied Commercial Transport Aircraft - Fourth Annual Flight Service Report. NASA CR-145326, April 1978.
6. Stone, R. H.; Flight Service Evaluation of Kevlar-49/Epoxy Composite Panels in Wide-Bodied Commercial Transport Aircraft - Fifth Annual Flight Service Report, NASA CR-159071, March 1979.

1. REPORT NO. NASA CR-159231	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE KEVLAR-49 EPOXY COMPOSITE PANELS IN WIDE-BODIED COMMERCIAL TRANSPORT AIRCRAFT - Sixth Annual Flight Service Report		5. REPORT DATE March 1980
7. AUTHOR(S) Robert H. Stone	6. PERFORMING ORG CODE	
9. PERFORMING ORGANIZATION NAME AND ADDRESS LOCKHEED-CALIFORNIA COMPANY P.O. BOX 561 BURBANK, CALIFORNIA 91520		8. PERFORMING ORG REPORT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. NASI-11621
		13. TYPE OF REPORT AND PERIOD COVERED Contractor Report, Jan.-Dec. 1979
14. SPONSORING AGENCY CODE		
15. SUPPLEMENTARY NOTES Annual Flight Service Report. Technical Monitor, Benson Dexter, Materials Division, NASA/Langley Research Center, Hampton, Virginia		
16. ABSTRACT Kevlar-49 fairing panels, installed as flight service components on three L-1011s, were inspected after 6 years' service. There are six Kevlar-49 panels on each aircraft: a left-hand and right-hand set of a wing-body sandwich fairing; a solid laminate under-wing fillet panel; and a 422 K (300°F) service aft engine fairing. The three L-1011s include one each in service with Eastern, Air Canada, and TWA. The fairings have accumulated a total of 45,000 hours, with one ship set having 17,700 hours service. The inspections were conducted at the airlines' major maintenance bases with the participation of Lockheed Engineering.		
The Kevlar-49 components were found to be performing satisfactorily in service with no major problems, or any condition requiring corrective action. The only defects noted were minor impact damage, and a minor degree of fastener hole fraying and elongation. These are for the most part comparable to damage noted on fiberglass fairings.		
The service history to date indicates that Kevlar-49 epoxy composite materials have satisfactory service characteristics for use in aircraft secondary structure.		
17. KEY WORDS (SUGGESTED BY AUTHOR(S)) COMPOSITES, KEVLAR-49, DURABILITY OF COMPOSITES, FLIGHT SERVICE EVALUATION	18. DISTRIBUTION STATEMENT Unclassified - Unlimited STAR Category 24	
19. SECURITY CLASSIF. (OF THIS REPORT) Unc.	20. SECURITY CLASSIF. (OF THIS PAGE) Unc.	21. NO. OF PAGES 22. PRICE*